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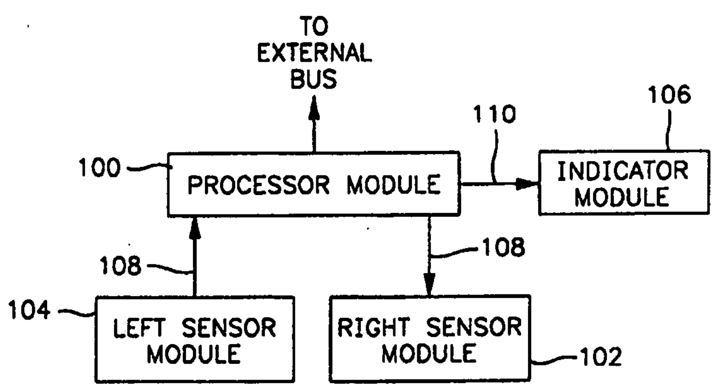


(57) Abstract

A system for detecting an object within a "Danger Zone". Two separate transceivers transmit and receive signals. First and second left channel signals and first and second right channel signals are each separated from one another. A signal is transmitted from a first antenna as a right channel continuous wave (CW) signal. Each of the transmitted signals reflects off objects which the signals strike. Upon receipt of reflections of each of the transmitted frequencies, each of the four channels is downconverted to generate four Doppler signals. By comparing the phase of the first right channel Doppler signal downconverted from the signals received at the first carrier frequency with the phase of the second right channel Doppler signal downconverted from the signals received at the second carrier frequency, the distance from the right antenna to each object can be determined. Likewise, by comparing the phase of the first and second left channel Doppler signals, the distance from the left antenna to each object can be determined. By comparing the distance to objects detected by the right channel signals with the distance to objects detected by the left channel signals, the exact location of each detected object can be determined with respect to the vehicle. Accordingly, a determination can be made as to whether each object is inside or outside a predefined Danger Zone.

METHOD AND APPARATUS FOR DETECTION OF OBJECTS PROXIMATE TO AN AUTOMOTIVE VEHICLE

TECHNICAL FIELD

This invention relates to automotive object detection systems, and more particularly to a object detection system using two sensors to detect objects behind a vehicle.

BACKGROUND ART

Detecting objects behind a vehicle, such as an automobile, truck, or other such vehicle, currently poses a problem to drivers of such vehicles. This is particularly problematic when the driver wishes to move the vehicle backward. Drivers occasionally back into an object or person that was not detected, causing damage to property or injury to persons.

A number of systems, devices, and methods are presently used to attempt to allow a driver of a vehicle to detect objects which are present in the rearward path of a vehicle. For example, most vehicles are equipped with at least one mirror on each side of the vehicle. Additionally, vehicles that have a clear optical path between a point generally centrally located near the top of the windshield or above the windshield are equipped with a rear view mirror. These mirrors allow the driver of the vehicle to see objects which might come into contact with the vehicle as the vehicle moves backward. However, these mirrors provide little assistance when objects are not within the field of vision provided by such mirrors. For example, objects which are relatively low to the ground, such as small children, fire hydrants, and small bicycles or tricycles may not be high enough to be visible by a driver of a vehicle, even if the driver views the images presented in all of the mirrors currently available on the vehicle. Furthermore, blind spots may exist in the field of vision that is provided by the combination of the driver twisting his head and looking in each of the mirrors.

Another solution to the problem of detecting objects which might pose a danger due to a collision between the vehicle and the object has been to use a radar system to

detect such objects. These systems work generally well for detecting objects that are approaching the vehicle at an alarming rate, or which are too close to the vehicle. However, in the case of a system for detecting objects behind a vehicle, the driver needs to detect only objects that are within a relatively small and sharply defined danger zone which essentially consists of a rectangular shaped region directly to the rear of the vehicle. It is important that such a system not cause an alarm condition to occur in response to objects that are near, but not within the danger zone. This poses a significant problem, particularly for conventional Doppler radar systems previously used to detect objects in the vicinity of a vehicle. That is, conventional Doppler systems rely on the relative motion between an object and the vehicle (or the system which transmits and receives a signal). Such Doppler systems can typically only detect range and velocity, and cannot detect the azimuth of an object. Accordingly, objects within a zone that conforms in shape the antenna pattern (e.g., spherical zones) can be distinguished from objects that are not within that zone. However, it is difficult to generate an antenna pattern that conforms to the desired shape of a danger zone. That is, one method for distinguishing between objects that are within the danger zone and those that are not, is to direct energy only into danger zone. However, it is not possible to design an antenna that can direct energy only into the danger zone and not into the surrounding area. Even so, it may be possible to distinguish between objects that are within the danger zone and those that are not if the amount of energy that reflect off objects in the danger zone differs significantly from the amount of energy that reflect off objects not in the danger zone. However, such transmission patterns are still too difficult to produce.

Furthermore, it is desirable to detect objects that are outside the danger zone in order to track such objects and thus validate the objects prior to the objects entering the danger zone. However, this can only be done if objects that are within the danger zone can be distinguished from objects that are near, but outside, the danger zone.

Further complicating the problem is the fact that the system needs to be able to distinguish objects within the danger zone that reflect small amounts of energy, such as a child, from objects outside the danger zone that reflect a large amount of energy, such as trucks. For example, a driver that is backing his vehicle along the side of a truck needs to know that a child is in the path of the vehicle. If the truck reflects so much

energy that the system cannot see the child, then the system will be unreliable, and may create a more dangerous condition than exists without the system.

Accordingly, there is a need for a system which is capable of detecting objects located generally behind a vehicle, and to distinguish objects that are located within a danger zone from objects that are located outside the danger zone regardless of the size of each such object.

DISCLOSURE OF INVENTION

The present invention is a system which can detect the presence of an object within a well-defined "Danger Zone" without falsely detecting objects that are close, but not within, the Danger Zone. The present invention uses two separate transceivers to transmit and receive signals, such as electromagnetic radio frequency (RF) waves, optical waves, acoustic waves, or other such signals which can be transmitted and the reflections of which can be received to detect the range to, and velocity of, objects with accuracy. In accordance with one embodiment of the present invention, pulsed signals are transmitted from a first antenna generally mounted on the right side of the Danger Zone (i.e., the "right channel" antenna) and from a second antenna generally mounted on the left side of the Danger Zone (i.e., the "left channel" antenna). In such an embodiment, pulses associated with a first right channel and having a first right channel carrier frequency are transmitted alternatively with pulses associated with a second right channel and having a second right channel carrier frequency. Transmission of the first and second right channel pulses are separated in time to prevent interference between them. That is, after transmission of the first right channel pulse and before transmission of the second right channel pulse, a first left channel pulse is transmitted from the left channel antenna at a first left channel carrier frequency. A second left channel pulse is then transmitted from the left channel antenna at the second left channel carrier frequency after transmission of the second right channel pulse. In this way, the first and second left channel signals and the first and second right channel signals are each separated from one another. In the case of the pulsed transmissions, the first and second right channel carrier frequencies are preferably the same as the first and second left channel carrier frequencies, respectively.

In accordance with another embodiment, an RF signal is transmitted from a first antenna as a right channel continuous wave (CW) signal. The right channel CW signal has a first right channel carrier frequency and a second right channel carrier frequency. The right CW signal alternates between the first and second right channel carrier frequency at a predetermined rate. Likewise, a left channel antenna transmits a left channel CW signal which alternates between a first and a second left channel frequency. The first and second frequencies of both the right and left channels are separated sufficiently to allow each signal to be selected and processed by a separate Doppler signal processing channel (e.g., a first and second right channel and a first and second left channel).

Regardless of whether the left and right channel signals are transmitted as CW or pulsed transmissions, each of the transmitted signals reflect off objects which the signals strike. Reflections of the signals are then received by each of the transceivers. Upon receipt of reflections of each of the transmitted frequencies, each of the four channels (i.e., first and second right channels and first and second left channels) are preferably downconverted to generate four Doppler signals. A fast Fourier transform (FFT) is performed on each Doppler signal to transform the received time domain information into frequency domain information. The frequency components of each of the Doppler signals indicates the relative velocity of the objects off of which the signal reflected. Different objects can be distinguished and separately tracked based upon differences in the relative velocity of each target with respect to each transceiver. In addition, the frequency domain information includes relative phase information. By comparing the phase of the first right channel Doppler signal down converted from the signals received at the first carrier frequency with the phase of the second right channel Doppler signal down converted from the signals received at the second carrier frequency, the distance from the right antenna to each object can be determined. Likewise, by comparing the phase of the first and second left channel Doppler signals, the distance from the left antenna to each object can be determined. By comparing the distance to objects detected by the right channel signals with the distance to objects detected by the left channel signals, the exact location of each detected object can be determined with

respect to the vehicle. Accordingly, a determination can be made as to whether each object is inside or outside a predefined Danger Zone.

In accordance with an alternative embodiment of the present invention, other methods are used to determine the range and relative velocity of detected targets. For example, a ramped CW signal may be used.

In addition, the present invention tracks objects by estimating where the object should be based upon (1) the previous location of the object, (2) the velocity at which the object was previously moving, and (3) the direction in which the object was moving as determined by the line (or arc) defined by the last two (or more) locations at which the object was detected.

In accordance with one embodiment of the present invention, each of the transceivers is preferably designed to maximize the amount of power that is transmitted and received in the Danger Zone, and to minimize the amount of power that is transmitted and received outside the Danger Zone.

Furthermore, in accordance with the preferred embodiment of the present invention, an indicator module is provided which ensures that at least one indicator will illuminate when power is lost to the control device to ensure that the operator of the host vehicle will be made aware that a power failure has occurred.

BRIEF DESCRIPTION OF DRAWING

The objects, advantages and features of this invention will be more readily appreciated from the following detailed description, when read in conjunction with the accompanying drawing, in which:

Figure 1 is a simplified block diagram of one embodiment of the present invention;

Figure 2 is a simplified block diagram of the Left Sensor Module;

Figure 3 is an illustration of the Processor Module 100 in accordance with one embodiment of the present invention;

Figure 4 is a schematic of an indicator drive circuit 500 in accordance with one embodiment of the present invention; and

Figures 5 and 6 illustrate one command cycle 400 of the protocol used in accordance with one embodiment of the present invention.

Like reference numbers and designations in the various drawings refer to like elements.

BEST MODE FOR CARRYING OUT THE INVENTION

Throughout this description, the preferred embodiment and examples shown should be considered as exemplars, rather than limitations on the present invention.

General Hardware Architecture of One Embodiment of the Present Invention

The present invention is a system for detection of objects in relatively close proximity to the rear of a vehicle. The inventive system uses two sensors to detect the presence of an object behind a vehicle, preferably when the vehicle is placed in reverse gear. Figure 1 is a simplified block diagram of one embodiment of the present invention. As shown in Figure 1, a Processor Module 100 is coupled by a communications signal path 108 to a Left Sensor Module 102 and a Right Sensor Module 104, and to an Indicator Module 106 by signal line 110.

Sensor Module Hardware Architecture

Figure 2 is a simplified block diagram of the Left Sensor Module 102. Each Sensor Module 102, 104 is essentially identical. Therefore, for the sake of brevity, only the Left Sensor Module 102 is described in detail. A detailed description of the operation of the Sensor Module 102 follows the complete description of the hardware architecture. A radio frequency output is generated by a dielectric resonant oscillator (DRO) 201. The output from the DRO 201 is coupled to a coupler circuit 203 which splits the power output from the DRO 201. An attenuator 205 is coupled to one output port of the coupler circuit 203. The output of the attenuator 205 is coupled to a transmit antenna 207. In an alternative embodiment of the present invention, the coupler circuit 203 is directly coupled to the transmit antenna 207 (i.e., no attenuator is provided). It should be understood that any hardware configuration may be used which provides a transmit signal which is generated and transmitted at a transmit frequency.

A second component to which the coupler circuit 203 is coupled is a mixer 209. The mixer 209 has an LO (local oscillator) port 208 coupled to the coupler circuit 203. The mixer 209 also has an RF port 210 coupled to a highpass filter (HPF) 211. The HPF 211 is coupled to a receive antenna 213. An IF (intermediate frequency) port 212 is coupled to an IF amplifier 216. The output from the IF amplifier 216 is coupled to an analog to digital (A/D) converter 218. The output from the A/D converter 218 is coupled to a control device 220, such as a microprocessor. In one embodiment of the present invention, the A/D converter 218 and the control device 220 are combined in one device, such as a 16C71 manufactured and distributed by MicroChip Technology of Chandler, Arizona. However, in an alternative embodiment, the A/D converter 218 and the control device 220 are discrete components. In accordance with an alternative embodiment, the control device 220 may be a circuit comprising discrete components, an Application Specific Integrated Circuit (ASIC), or a state machine.

In accordance with one embodiment of the present invention, a frequency control signal is coupled to the DRO from the control device 220 on frequency control signal 222. The frequency control signal allows the control device to modulate the frequency output from the DRO. In one embodiment of the present invention the control device causes the DRO 201 to generate a first and second channel frequency. In addition, a second control signal on a gain control signal line 224 is preferably coupled from the control device 220 to the IF amplifier 216 to control the gain of the IF amplifier 216. The control device 220 is also coupled to the Processor Module 100 via the communications signal path 108. The communications path 108 is preferably a differential serial data link.

Processor Module Hardware Architecture

The following is a description of the hardware architecture of a Processor Module in accordance with one embodiment of the present invention. A description of the operation of the Processor Module 100 follows the complete description of the hardware architecture.

Figure 3 is an illustration of the Processor Module 100 in accordance with one embodiment of the present invention. The Processor Module 100 includes a PM Control

Device 301, such as a digital signal processor (DSP), which is capable of performing a fast Fourier transform (FFT). However, it should be clear that the PM Control Device 301 may be any device that is capable of mapping signals from time domain to frequency domain. In accordance with one embodiment of the present invention, the PM Control Device 301 is a TMS320C52 integrated circuit chip manufactured and distributed by Texas Instruments, Inc. The PM Control Device 301 is coupled to a memory device, such as a random access memory (RAM) 302, and read-only memory (ROM) 304. The PM Control Device 301 is also coupled to a Sensor Communications Interface 303. The Sensor Communications Interface 303 preferably includes a Command Word register 305, a Sensor Control register 307, a Sensor Status register 309, a Left Channel F1 Signal register 311, a Left Channel F2 Signal register 313, a Right Channel F1 Signal register 315, and a Right Channel F2 Signal register 317. The PM Control Device 301 has access to write to the command word register 305 and the sensor control register 307. In addition, the PM Control Device 301 can read each of the registers 305, 307, 309, 311, 313, 315, 317 in the Sensor Communications Interface 303.

The PM Control Device 301 is also coupled to a serial port 319. The Processor Module 100 can communicate with other devices within a "host vehicle" (i.e., the vehicle in which the system is mounted) via the serial port 319. In addition, the PM Control Device 301 is coupled to a nonvolatile memory interface device, such as a non-volatile RAM (random access memory) interface 321. The nonvolatile memory interface 321 is coupled to a nonvolatile memory device 323, such as a non-volatile random access memory device, for example, an EEPROM (electrically erasable programmable read only memory), a disk drive, charge-coupled device with battery back-up, etc. An Interrupt Status Register 325 is also preferably provided. When either the serial port 319 or the nonvolatile memory interface 321 require servicing by the PM Control Device 301, an interrupt is generated. The device requiring service writes to the Interrupt Status Register 325 to indicate the nature of the interrupt required.

An LED (light emitting diode) drive circuit 237 is also provided within the Processor Module 100. The LED drive circuit 237 is coupled to an indicator control register 239. The indicator control register 239 is coupled to, and the contents may be

updated by, the PM Control Device 301. An LED monitoring circuit 241 is also coupled between the LED drive circuit 237 and the PM Control Device.

Indicator Module Hardware Architecture

An Indicator Module 106 is coupled to the Processor Module 100. The Indicator Module 106 preferably includes the LEDs which are used to indicate to the driver of the host vehicle whether the system is active, an object is within the Danger Zone, or an object is present, but outside the Danger Zone. However, in an alternative embodiment of the present invention, the Indicator Module 106 may include any means for indicating any number of conditions including some or all of the preferred conditions, and any number of other conditions not expressly stated herein and which are to be conveyed to the driver of the host vehicle through the system.

In accordance with the preferred embodiment of the present invention, the Indicator Module 106 ensures that at least one indicator will illuminate when power is lost to the PM Control Device 301. In this way, the operator of the host vehicle will be made aware that a power failure has occurred. Figure 4 is a schematic of one embodiment of the inventive circuit used to activate the indicator upon loss of power to the PM Control Device 301. In accordance with the embodiment of the present invention shown in Figure 4, two transistors 501,503 are used in the inventive drive circuit 500. Under normal conditions, a supply voltage within the Indicator Module 106 is coupled to a first terminal of an indicator 505. A second terminal of the indicator 505 is coupled to the anode of a diode 507. A cathode of the diode 507 is coupled to the collector of an NPN transistor 503. The cathode of the diode 507 is also coupled to the first terminal of a high resistance resistor 511. The second terminal of the high resistance resistor 511 is coupled to the base of the transistor 503. The emitter of the transistor 503 is coupled to a first terminal of a low resistance resistor 513. The second terminal of the low resistance resistor 513 is coupled to ground. The base of the transistor 503 is also coupled to the collector of the transistor 501. The collector of the transistor 501 is also coupled to a first terminal of the high resistance resistor 515. The second terminal of the high resistance resistor 515 is coupled to the cathode of a diode 517. An anode of the diode 517 is coupled to the voltage supply source within the

Processor Module 100. The emitter of transistor 501 is coupled to ground. The base of transistor 501 is coupled to a first terminal of a high resistance resistor 519. The second terminal of the high resistance resistor 519 is coupled to an indicator control signal produced by the Processor Module 100.

If the processor module voltage supply (V_{CC})is at an operating level, the indicator 505 is activated by applying a low voltage signal to the base of the transistor 501. In response, the transistor 501 conducts current from the collector to ground bringing the voltage level at the base of the transistor 503 to a low voltage state. In response, the transistor 503 does not conduct current from its collector to ground. Accordingly, a high voltage level is presented to the base of the transistor 503. Consequently, the transistor 503 conducts current from its collector through the transistor 503 and the low resistance resistor 513 to ground. Accordingly, current is drawn through the indicator 505 at a sufficiently high level to activate the indicator 505. Alternatively, the indicator may be deactivated by applying a high voltage level to the base of the transistor 501, causing the transistor to conduct from its collector to ground. This results in a low voltage state at the base of the transistor 503. According, the transistor 503 ceases conducting. While a small current will flow through the indicator 505, the diode 507, the high resistance resistor 511, and the transistor 501, this current will be insufficient to activate the indicator 505 due to the high resistance of the resistor 511.

The circuit shown in Figure 4 insures that the indicator 505 will be activated if the power supply to the Processor Module 100 fails. This can be understood by noting that upon loss of power within the processor module, transistor 501 will cease conducting, since the inductor control signal from the Processor Module 100 will float. Accordingly transistor 503 will begin conducting due to the bias provided to the base of the transistor 503 through the high resistance resistor 511.

Operation of the Sensor Module

In accordance with one embodiment of the present invention, the Sensor Modules 102, 104 remain essentially idle until commands are received from the Processor Module 100 over the communication signal path 108. It should be noted that in

alternative embodiments the Sensor Modules 102, 104 may be continuously transmitting signals, performing self tests, etc. In accordance with one embodiment of the present invention, the communication signal path 108 that couples the control device 220 of the Sensor Modules 102, 104 to the Serial Communications Interface 303 is a twisted pair in accordance with IEEE standard RS-485. Communications between the Processor Module 100 and the Sensor Modules 102, 104 conform to a half-duplex serial communication protocol. However, it will be understood by those skilled in the art that any communications scheme and/or protocol may be used to communicate information between the Sensor Modules 102, 104 and the Processor Module 100.

Figures 5 and 6 illustrate one command cycle 400 of the protocol used to communicate between the Processor Module 100 and a Sensor Module 102, 104 in accordance with one embodiment of the present invention. In accordance with the protocol used in one embodiment of the present invention, a command cycle includes a start bit 401, followed by a command field 403 comprising three bits. A 26 bit long response field 404 follows the command field 403.

A three bit command transmitted in the command field 403 causes the control device to respond in one of the following ways: (1) return a digital value output from the A/D converter 218 corresponding to the amplitude of a first channel Doppler signal and a second channel Doppler signal to the Processor Module 100 in the next command cycle; (2) select high gain mode (i.e., cause the IF amplifier to operate with a relatively high gain); (3) select low gain mode (i.e., cause the IF amplifier to operate with a relatively high gain); (4) select normal output frequency; (5) select anti-jam frequency; (6) return Built-In-Test (BIT) value; and (7) return frequency deviation correction value. In accordance with one embodiment of the present invention, a command extension code is defined which allows commands presented in the command field of a second command cycle to be interpreted in a manner which differs from the manner in which those commands would be interpreted if the three bits of the previous command were not equal to the extension command. Such extension commands may be sent in any number of consecutive command cycles to extend the number of commands that can be defined. Accordingly, any number of commands may be defined using consecutive three bit command fields 403.

It should be understood that the length of the command field 403 and the commands used with alternative embodiments of the invention may differ from those described for the particular embodiment disclosed herein. For example, in an alternative embodiment of the present invention in which range is determined by means other than by detecting a Doppler shift, the commands will differ. Furthermore, the particular features that are present in the invention will dictate the commands that are required. Therefore, for example, if particular BIT tests are performed and the results of such BIT tests may be individually requested, then there may be a command which is particularized to cause the Sensor Module 102 to respond by sending the results of those tests. Furthermore, the protocol that is used may vary from the protocol that is disclosed herein without departing from the scope of the present invention.

In response to at least some of the commands, a value is to be returned to the Processor Module 100. The value that is to be returned is communicated to the Processor Module 100 in the 26 bit time slots which comprise the response field 404. However, the values to be returned in response to at least some of the commands require more time then is provided by the single bit time slot 405 which is skipped between the command 403 and the response field 404. Therefore, in most cases, the information that is to be returned in response to a command 403 is returned during the response field 404 of the next command cycle 400. Each bit time is approximately 10.8 μs in duration. No information is transmitted during the fifth bit time 405. This provides time for the bus to reverse direction between the command 403 and the response field 404. Similarly, no information is transmitted during the last bit of each command cycle 407. Accordingly, each command cycle is 32 bits x 10.8 μs = 345.6 μs in duration. A subsequent command cycle may begin immediately after the end of the last command cycle 400.

Return Digital Value Command

In accordance with one embodiment of the present invention, the control device 220 receives a "Return Digital Value" command from the Processor Module 100 to return a digital value indicative of the amplitude of the signals received by the sensor module 102. Range and relative velocity information are preferably derived by processing the digital values received on a first and second channel (as will be discussed

in greater detail below). The digital value is preferably determined by transmitting a frequency shift key (FSK) modulated transmit signal and comparing a received reflection of that signal to the transmitted signal. That is, the control device 220 outputs a frequency control signal 409 on the frequency control signal line 222 to cause the DRO 201 to output a signal (see Figure 2). In accordance with one embodiment of the present invention, a first pulse is output at an F1 frequency during the sixth bit time (i.e., the first bit time of the response field 404). A second pulse is output at an F2 frequency during the 10th bit time (i.e., four bit times after the first pulse). In accordance with one embodiment of the present invention, a bias voltage signal 411 to the DRO 201 is used to cause the DRO to begin oscillating. Accordingly, a first bias voltage pulse 413 occurs during the sixth bit time. A second bias voltage pulse 415 occurs during the tenth bit time. The control device 220 is coupled to the bias input of the DRO 201 via control signal line 226 (see Figure 2). The voltage 409 applied by the control device 220 on signal line 222 to a varactor (not shown) within the DRO circuitry determines the frequency at which the DRO 201 will oscillate.

The control device 220 outputs a voltage 417 to the DRO on frequency control line 222 starting at the beginning of the fifth bit time and ending at the end of the eighth bit time. The voltage pulse 413 is applied to bias the DRO 201 during the sixth bit time, thus causing the DRO 201 to output an F1 frequency pulse during only the sixth bit time (i.e., concurrent with the first bit time of the response field 404).

In accordance with one embodiment of the present invention, at the ninth bit time, the control device 220 changes the voltage 419 applied to the frequency control signal line 222 to cause the DRO 201 to change to the F2 frequency. At the tenth bit time, the control device applies the bias voltage pulse 415 to the control signal line 226 to cause the DRO 201 to output a second pulse, the second pulse being at the F2 frequency. Four such F1 pulses and four F2 pulses are alternately transmitted from the Sensor Module 102 in response to each Return Digital Value command received by the control device 220 from the Processor Module 100, as can be seen by the eight bias voltage pulses 413, 415, 421, 423, 425, 427, 429, 431 applied to the DRO 201. Each such pulse lasts for 10.8 μs, beginning 32.4 μs after previous pulse ends. Accordingly, a total of 8 pulses are transmitted in response to one command cycle. It should be noted

that the last bias voltage pulse 431 occurs in the second bit time of the next command cycle (i.e., during the time the next command is being received, assuming that another command is sent from the PM Control Device 301 immediately after the last command).

In accordance with an alternative embodiment of the present invention, the transmit signal may be a ramped signal which begins at a relatively low frequency and increases in frequency to a relatively high frequency. Such ramping systems rely on the difference between the transmit frequency and the frequency of the received reflection of the transmit signal received after a delay which is equal to the amount of time required for the signal to propagate from the Sensor Module 102 to a target and reflect back to the Sensor Module 102. It will be understood by those skilled in the art that other schemes for determining the range and relative velocity of targets may be used, such as pulsed systems, I and Q quadrature systems, etc.

In accordance with one embodiment of the present invention, the DRO output signal is a 24.125 GHz signal which is FSK modulated between the F1 frequency and the F2 frequency with a deviation in the range of about 2.46 - 10.0 MHz (i.e., the difference between the F1 and F2 frequency is in the range 2.46 - 10.0 MHz). At 24.125 GHz fundamental frequency, there is a 72 Hz/mph Doppler shift in frequency. Range to targets is determined by detecting the phase difference between the Doppler signal which results from the Doppler shifting of the transmit signal at the high end of the deviation range and the Doppler signal which results from the Doppler shifting of the transmit signal at the low end of the deviation range. The phase difference is cyclical over a distance which is a function of the difference between the high and low transmit frequencies. Therefore, the phase difference between the transmit signals that reflect off a target at x ft. will be the same as the phase difference between the same transmit signals which reflect off a target at $(2n)\,y + y - x$ ft. and $(2n - 1)\,y + x$ ft. where y is the range at which the phase difference is equal to 180 degrees and n is an integer. At lower deviation frequencies, a larger range can be determined unambiguously (i.e., 100 ft. for deviation of 2.46 MHz verses 25 ft. for deviation of 10 MHz). However, at higher deviation frequencies, the accuracy with which the range to a target can be determined is greater (i.e., 0.125 ft. for 10 MHz, verses 0.5 ft. for 2.46 MHz at a signal to noise

ratio of 30 dB). Therefore, a tradeoff must be made between range accuracy and range ambiguity.

The signal output from the DRO 201 is routed through the coupler 203 and the attenuator 205 to the transmit antenna 207. In accordance with one embodiment of the present invention, the transmit antenna 207 is preferably designed to maximize the amount of power that is transmitted and received in the Danger Zone, and to minimize the amount of power that is transmitted and received outside the Danger Zone. Alteratively, in the case in which targets are to be tracked prior to entering the Danger Zone, the antenna 207 is designed to transmit power in a pattern that closely resembles the configuration of the Danger Zone, but which extends beyond the Danger Zone to a desired extent to allow targets to be tracked prior to entry into the Danger Zone.

A portion of the signal is routed by the coupler 203 to the mixer 209 (see Figure 2). The attenuator 205 acts as a pad between the DRO 201 and the transmit antenna 207. The signal is transmitted out of the transmit antenna 207 and reflects off objects which are in the vicinity of the host vehicle. The reflections of the transmitted signal are received by the receive antenna 213. That is, the signals received by the receive antenna 213 include the transmitted signals which have reflected off objects in the vicinity of the host vehicle. These signals will have been Doppler shifted if the objects are in relative motion with respect to the host vehicle. The high pass filter 211 rejects undesirable low frequency signals (signals that are not of interest), allowing only signals that are in the range of the transmitted signals to pass. It will be clear to those skilled in the art that a number of filter schemes may be implemented to select only those signals that are of interest to the present invention. The output from the high pass filter 211 is preferably coupled to the RF input 210 of the mixer 209. The portion of the DRO output signal that is coupled to the mixer 209 by the coupler 203 is preferably applied to the LO input port 208 of the mixer 209 to down convert the received signals to their Doppler frequencies.

In the preferred embodiment, the output from the mixer 209 is taken from the IF port 212 and coupled to the IF amplifier 216 which increases the strength of the Doppler signals output from the mixer 209. The gain of the IF amplifier 116 is adjustable under the control of the Processor Module 100. The signals output from the

IF amplifier 216 are input to the A/D converter 218. In accordance with one embodiment of the present invention, a demultiplexing switch is used to direct the F1 pulses to a first channel of the A/D converter 218, and the F2 pulses to a second channel of the A/D converter 218.

That is, the demultiplexing switch is coupled to the control device 220 and receives a control signal that synchronizes the switch to the DRO 201. During the time the DRO 201 is outputting the F1 frequency, the output from the IF Amplifier 216 is coupled to the first channel of the A/D converter 218. During the time the DRO 201 is outputting the F2 frequency, the output from the IF Amplifier 216 is coupled to the second channel of the A/D converter 218. The A/D converter 218 samples the signal once during each pulse (i.e., at a rate of 2.9 KHz for each channel). The fact that the received signal is only sampled for a short period of time which coincides with a relatively short pulse of the transmit signal. Therefore, the likelihood that two systems will interfere with each other is reduced. Furthermore, a bandwidth of ± 50 MHz is currently allocated by the Federal Communications Commission (FCC) for these purposes. Thus, at a deviation frequency of 2.45 MHz, 40 different frequencies may be used, further reducing the likelihood that two systems will interfere.

The digitized output from the A/D converter 218 is coupled to the control device 220. In accordance with the system in which F1 and F2 signals are digitized in different channels, the outputs from each channel are output in interleaved form, such that a first word is output from the first A/D channel and then a first word is output from the second A/D channel, followed by a second word from the first A/D channel and then a second word from the second A/D channel. Alternatively, a single channel A/D converter digitizes all eight pulses received by the Sensor Module 102.

In accordance with one embodiment of the present invention, after receiving a Return Digital Value command, the control device 220 communicates the amplitude of the received signals to the Processor Module 100 during the response field 404 of the next command cycle 400 due to the amount of time required to convert the analog value input to the A/D 218 into a digital value output from the A/D 218.

In accordance with the embodiment of the present invention in which the transmit frequency alternates between an F1 frequency and an F2 frequency, the first 10 bits of

the response field 404 are used to communicate the digital value of the arithmetic sum of the digital values of the amplitudes of the received reflections of the four F1 frequency pulses transmitted during the previous command cycle. The subsequent three bits are used to echo the command. Likewise, the next 10 bits of the response field 404 (i.e., bits 14 - 23) are used to communicate the arithmetic sum of the digital values of the amplitude of the received reflections of the four F2 frequency pulses transmitted during the previous command cycle. The last three bits of the response field 404 are used to send an inverted version of the command. The echoed command bits serve as an acknowledgement that the Sensor Module 102 received the command.

Since the Sensor Module 102 has no means by which to initiate a command cycle, the Processor Module 100 must initiate a second command cycle in order to receive the digital values associated with the pulses that were transmitted during the first command cycle. Accordingly, if a second set of pulses are not to be transmitted, the Processor Module 100 may initiate a second command cycle by sending a Null command to the Sensor Module 100. A Null command does not cause the control processor 220 to perform any function except return the values associated with the command sent in the last command cycle.

In an alternative embodiment of the present invention, the frequencies of the transmit and receive signals could be detected directly without down converting the signals, thus eliminating the need for the mixer 209. That is, the output from the antenna may be amplified and digitized without, or prior to the downconversion step. However, downconversion of the received signals is typically desirable. In accordance with an alternative embodiment, the downconversion of the received signals may be done in two or more steps. However, the fact that the output from the DRO 201 can be used directly as the local oscillator signal in a single step conversion makes the architecture shown in Figure 2 the preferred embodiment. Nonetheless, it should be understood that any means by which the distance between the Sensor Module 102 and a target can be detected would be within the scope of the present invention. For example, a ramped CW signal may be transmitted and downconverted to provide information regarding range and relative velocity. Furthermore, light or sound waves may be used to determine the distance between the Sensor Module 102 and a target.

Select High/Low Gain Mode Command

In accordance with the preferred embodiment, if the Processor Module 100 determines that the A/D converter 218 is near overflow (i.e., whether the analog voltages input to the converter 218 are too large), then the Processor Module 100 preferably waits until the end of a block of data has been sent (i.e., data sent from the sensor module is processed in blocks of 256 words, as is described in greater detail below). At the end of a block of data, the processor module 100 sends a command over the serial communication path 108 to reduce the gain of the amplifier 216. In response to the receipt of the command, the sensor device 102 continues to transmit a transmit signal in the same manner as if a Return Digital Value command had been received by the sensor module 102. In addition, the next command will return the digitized value of the amplitude of the received signal, just as if a Return Digital Value command had been received. However, the control device 220 outputs a gain control signal on the gain control signal line 224 which reduces the gain of the IF amplifier 216 (if the gain is not already at the lowest value). Once the gain has been changed, the gain is remains set at that level for each subsequent transmit/receive cycle until a new gain command is received.

By having the Processor Module 100 assume responsibility for determining when to adjust the gain of the amplifier 218, the gain does not change in the middle of a block of data. Alternatively, the control device 220 may directly determine whether the gain should be reduced based upon the amplitude of the received signal (i.e., the digital value of the output from the A/D converter 218). In yet another embodiment, the gain of the amplifier is fixed (i.e., does not vary as a function of the values output from the A/D).

Likewise, if the signal output from the control device 220 to the Processor Module 100 is below a predetermined digital value, a command is sent from the Processor Module 100 to the control device 220 at the end of a block of data. In response, the control device 220 will provide a gain control signal to the IF amplifier to cause the gain of the IF amplifier 216 to be increased (if the gain is not already at its highest level). Alternatively, the control device 220 may directly determine that the gain is too low and cause the gain to be increased. In accordance with one embodiment of the present invention, the IF amplifier 216 has only two gain values. Therefore, the gain

control signal may be a single bit digital control signal. In an alternative embodiment, the IF amplifier 216 may have any number of gain settings. It will be clear to those skilled in the art, that an indication of the gain level of the IF amplifier is preferably appended to the digital value output from the A/D converter 218.

Select Normal Frequency/Anti-Jam Frequency Command

In accordance with the preferred embodiment, if the Processor Module 100 determines that interference is present at the frequency that is being transmitted, then the Processor Module 100 preferably waits until the end of a block of data has been sent. At the end of a block of data, the processor module 100 sends a "Frequency" command over the serial communication path 108 to change the transmitter frequency to avoid the interference. In accordance one embodiment of the present invention, the control device can control the DRO 201 to transmit within one of two ranges. However, the number of ranges that are provided will depend upon the bandwidth that is available, the type of modulation used, and a tradeoff between cost and function.

In response to receipt of the Frequency command, the sensor device 102 continues to transmit a transmit signal in the same manner as if a Return Digital Value command had been received by the Sensor Module 102. In addition, the next command will return the digitized value of the amplitude of the received signal, just as if a Return Digital Value command had been received. However, the control device 220 outputs frequency control signals on the frequency control signal line 222 which cause the frequency of the transmit signals to fall outside the band of frequencies that are experiencing the interference. Once the frequency has been changed, the frequency remains set for each subsequent transmit/receive cycle until a new frequency command is received.

Built-In-Test (BIT) Command

Upon receipt of a BIT command, the control device 220 performs tests which determine the general functional status of the sensor device. For example, in accordance with one embodiment of the present invention, the downconverter 209 has a characteristic DC voltage offset. This offset is preferably removed by the DC servo

circuit 214. The DC servo circuit 214 is essentially a servo loop which detects the DC offset voltage, generates a voltage that is equal and opposite to the DC offset, and sums this voltage with the output from the downconverter 209 to remove the DC offset from the output. In response to the receipt of a BIT command, the control device 220 activates the DRO 201 to output a transmit signal. The transmit signal is transmitted and a reflection of the transmit signal is received and downconverted. With the downconverter 209 active, the servo voltage that is summed with the output from the downconverter 209 to eliminate the DC offset is also coupled to an A/D port of the control device 220 via signal line 215. The control device 220 preferably has a discrete A/D input port that is available to accept the servo voltage output from the DC servo circuit 214. The control device 220 digitizes the servo voltage and provides the digitized value to the Processor Module 100. In accordance with one embodiment of the present invention, the digital value is transmitted back to the Processor Module 100 during bit times 19 - 31 (i.e., the second half of the response field 404) of the same command cycle during which the BIT command was sent. Preferably, the first 10 bits of the response field 404 are filled with zeros. The BIT command is echoed during the next three bits of the Data Section, and the last three bits of the Data Section.

Return Frequency Deviation Correction Command

Upon receipt of a command to return the frequency deviation correction value, the control device 220 reads a value from a frequency deviation register 221 and transmits that value to the Processor Module 100. The frequency deviation register 221 is loaded with a value by the manufacturer after performing initial performance tests during which the amount of deviation which occurs in the frequency output from the DRO 201 is measured. That is, the DRO 201 is commanded to output a frequency. The frequency that is actually output is measured. The difference between the frequency that is actually output and the frequency requested is then loaded into the frequency deviation register 221. In one embodiment of the present invention, the deviation correction value is only determined for one frequency. However, in an alternative embodiment, the deviation frequency can be determined at selected points along the transmit band (i.e., at the low and high frequency ends of the transmit band, or at normal F1 and F2

frequency and at the anti-jam F1 and F2 frequency). Further details regarding frequency deviation correction will be provided below in the section related to operation of the Processor Module 100.

Operation of the Processor Module

Power is applied to the Processor Module 100 when the vehicle key is turned to the ON position (i.e., when electrical power is made available to accessories throughout the vehicle). Upon application of power, the PM Control Device 301 executes a boot-up routine. In the preferred embodiment of the present invention, the boot-up routine is completely executed in the first 500 milliseconds after power is applied. The boot-up routine includes: (1) Processor Module BIT tests, such tests of the memory device 302 within the Processor Module 100; (2) loading executable code into the memory device 302 from which the code is to be executed during normal operation; (3) values associated with global variables and constants are initialized; (4) Interrupts are reset and enabled; and (5) initialization routine are run for initializing timers, diagnostics, lights, and track/warning routines.

Upon completion of the boot-up routine, the PM Control Device 301 preferably enters either Active mode or Standby mode. In one embodiment of the present invention, the PM Control Device 301 enters Active mode whenever the host vehicle is placed in reverse gear. The PM Control Device will be in Standby mode at all other times.

Active Mode

When in Active Mode, the PM Control Device 301 preferably sends continuous Return Digital Value commands to both the right and the left Sensor Module 102 by initiating a continuous mode of operation for each Sensor Module 102. To send the Return Digital Value commands, the PM Control Device 301 loads a Return Digital Value command into both the right and left command word register 305 within the Sensor Communications Interface 303. The least significant bit (i.e., the "Single/Continuous Mode" bit) of the right and left Sensor Control Register 307 within the Sensor Communications Interface 303 are then set. In response to setting the Single/Continuous Mode bit of each Sensor Control Register 307, the Sensor

Communications Interface 303 continuously sends command cycles to each Sensor Module 102 in which the value loaded in the right Command Word register 305 determines the value of the command field 403 sent to the right Sensor Module 102, and the value loaded in the left Command Word register 305 determines the value of the command field sent to the left Sensor Module 102.

Transfer of Digital Values

As described above, in accordance with one embodiment of the present invention, each Sensor Module 102 responds to a Return Digital Value command sent in a first command cycle by sending a digital value representative of the amplitude of reflections of a transmit signal in the response field 404 (see Figure 5) of a second command cycle. The first three bits of the response field 404 of the second command cycle are an echo of the command of the first command cycle. The next 10 bits (hereafter referred to as the "F1 Digital Value") represent the sum of the amplitude of four pulses transmitted by the Sensor Module 102 at a first frequency (i.e., the "F1" frequency) in response to the Return Digital Value command of the first command cycle. The next 10 bits (hereafter referred to as the "f2 Digital Value") represent the sum of the amplitude of the four pulses that were transmitted by the Sensor Module 102 at a second frequency (i.e., the "F2" frequency) in response to the Return Digital Value command of the first command cycle.

As the contents of the response field 404 of each command cycle are received by the Sensor Communications Interface 303 from the left Sensor Module 102, the value of each F1 Digital Value is stored in the Left Channel F1 Signal register 311 and each F2 Digital Value is stored in the Left Channel F2 Signal register 313. Likewise, the values of the Right Channel F1 and F2 Digital Values are stored in the Signal registers 315, 317.

Processing of Digital Values

In accordance with the preferred embodiment of the present invention, the PM Control Device 301 is interrupted by the Sensor Communications Interface 303 only after the first 512 Digital Values have been received and stored in each of the four Signal registers 311, 313, 315, 317, and each time an addition 256 Digital Values are received and stored in each of the registers 311, 313, 315, 317. In the preferred embodiment, the interrupt is generated by setting a bit within the Sensor Status register 309 associated with the particular sensor that has completely transmitted 256 Digital Values associated with of both F1 and F2. Thus, a sufficient number of Digital Values will have been collected to allow the PM Control Device 301 to perform an accurate FFT operation, and thus map the time domain Digital Values into the frequency domain. It should be understood that in accordance with an alternative embodiment of the present invention, an interrupt may be provided when any other number of Digital Values have been stored in the Signal registers 311, 313, 315, 317.

Each of the Digital Values stored in the Signal registers 311, 313, 315, 317 is preferably divided by four prior to storage. However, in an alternative embodiment, the Digital Values may be scaled either by the PM Control Device 301 after being read, or by a right shift of the data while being coupled from the Sensor Communications Interface 303 to the PM Control Device 303. The division by four returns each Digital Value (which currently represents the sum of four samples) to a value that is the average of the four samples that were summed by the Sensor Module 102 in generating that Digital Value. By taking the average of four amplitude values, any random noise that is present in each value is averaged out.

An interrupt is generated when 512 Digital Values (referred to as a "block" of data) are available to be mapped by operation of an FFT from the time domain to the frequency domain. Prior to performing the FFT, each block of data undergoes a D.C. removal algorithm in which the average of the high and low amplitude values from within the block of data is subtracted from each amplitude value. In addition, the data block is prescaled to normalize the values of each block. That is, each value is multiplied by a constant to cause the highest and lowest points to fill the full digital range available for the values of the block. An operations on such prescaled data is

commonly referred to as a "block floating point" operation. Block floating point operations reduce the effect of quantization noise, which results from the fact that there are not an infinite number of digits used to express the amplitude of each Digital Value in the data block. Each subsequent interrupt will cause a next FFT to be performed using the most recent 256 Digital Values and the 256 Digital Values received just prior to receipt of the most recent values. Accordingly, there is preferably a 50% overlap in the mapping of the amplitude values into frequency values.

In accordance with the preferred embodiment of the present invention, since the time domain signal only has real components, a 256-point FFT operation with additional signal splitting and decoding operation can be used to compute the FFT of the 512 sample input signal without computation redundancy, as is known in the art. That is, a discrete FFT of an N-point real valued data sequence may be computed by scrambling the data sequence into an N/2 point complex valued sequence, followed by performing an N/2 point complex FFT and then unscrambling the FFT output to that of an N-point FFT output. Such 3 stage processes are known and provide better computation efficiency and reduced computation buffer memory requirements. A 512 point FFT results in Spectrum data that has a resolution of 5.6 Hz, or 0.078 mph.

In accordance with the preferred embodiment in which Digital Values are coupled from the Sensor Module at a rate of 2.9 KHz (i.e., once per command cycle of 344 μs), one FFT operation is performed for each frequency of each sensor every 88 ms. That is, a total of four FFTs are performed every 88 ms; one for Right Channel F1 data, one for Right Channel F2 data, one for Left Channel F1 data, and one for Left Channel F2 data. The rate of 2.9 KHz ensures that the Nyquest sampling criteria for detecting a frequency of 1445 KHz will be met. The frequency 1445 KHz is the Doppler frequency that results from a 20 mph relative velocity between the host vehicle and a target with a transmit frequency of 24.125 GHz.

The output from the FFT operation performed by the PM Control Device 301 is referred to as a block of "Spectrum" data. Each block of Spectrum data is further processed to determine the noise floor of the signals received by each Sensor Module 102, the number of potential targets represented in the block, and the number of qualified targets represented by the block.

Noise Floor Determination

A determination as to the level of the noise floor is preferably made based upon the block of Spectrum data. In accordance with the preferred embodiment, the noise floor is computed in eight separate frequency bands. Initially, a biased average is computed for each of the eight frequency bands. The biased average is then applied to a filter, such as an infinite impulse response (IIR) filter, to determine an estimated noise floor value for each frequency band. In one alternative embodiment of the present invention, the filter is a slew limited filter. In another embodiment of the present invention, the filter may be a simple 1 pole low pass filter. The biasing may be done by calculating a first average of the amplitude across the band. A threshold is then set at a value a predetermined level above the first average of each of the amplitude values in the first band. Any signals above this threshold are either disregarded, or alteratively replaced by the level of the threshold (since the likelihood is that these signals are targets and not noise). The result of this second average calculation is then filtered using the IIR filter to determine the noise floor. The noise floor for the first band is then used to determine the threshold to be used in clipping the second band to determine the noise floor of the second band. Each subsequent band is then calculated using the noise floor of the previous band multiplied by a scaling factor to determine the threshold for the subsequent band.

In accordance with one embodiment of the present invention, heuristic rules are applied to limit the discontinuity in the noise floor between adjacent bands. For example, it can be assumed that the noise at band k is greater than or equal to the noise at band $k + 1$ (the adjacent higher frequency). Also, the noise estimate at band k can be limited to a pre-defined scale factor times the noise estimate at the band $k + 1$. Also, noise bands at lower frequencies are narrower and rely on an inadequate number of FFT points in its estimate. The noise estimate for these lower frequency bands can be projected from a higher frequency band as follows: (1) noise estimate at band 3 = noise estimate at band 4 times a scale factor, $n3$; (2) noise estimate at band 2 = noise estimate at band 3 times a scale factor, $n2$; (3) noise estimate at band 1 = noise estimate at band 2 times a scale factor, $n1$.

Furthermore, the noise floor estimate may be averaged over time to further reduce the effects of high amplitude short term signals within a band. Whenever the gain or frequencies at which the Sensor Module 102 was previously operating have been commanded to change, the noise floor will begin without reliance on the previously calculated Spectrum data.

Determination of Target Characteristics

Once the noise floor has been determined, the PM Control Device 301 determines the relative distance and speed of a predetermined number of targets which have been detected as peaks that are at least 15 dB above the noise floor. In the embodiment of the present invention in which an FSK modulated transmit signal is used, the validity of a target is first checked by ensuring that the amount of power that was received at the Doppler frequency by the first channel is within 5 dB of the power received at that Doppler frequency in the second channel. Typically, peaks in the Spectrum data that are the result of thermal noise or EMI do not have similar power levels in both channels. Therefore, ensuring that the power that was received in each channel is nearly equal (e.g., within 5 dB) eliminates a number of false targets.

In an alternative embodiment of the present invention, radar cross section (RCS) is also determined. In accordance with one embodiment of the present invention, the characteristics of 20 targets are determined. In accordance with the embodiment of the present invention in which Doppler FSK techniques are used to determine the range of targets, the range is determined by comparing the phase of each received F1 signal to the phase of that received F2 signal which has the same Doppler frequency as the received F1 signal. The relative speed is determined by directly determining the Doppler frequency of the signals received. The RCS is determined based upon the amplitude and range of the received signals.

Target Tracking

Once the PM Control Device 301 has determined the target characteristics for each target detected in the most recent block of Spectrum data, the PM Control Device 301 compares those target characteristics with the target characteristics determined for

at least the previous block of Spectrum data. The current range, relative speed, and RCS of each valid target determined from the last block of Spectrum data should appear reasonably close in value to the range, relative speed, and RCS of a target detected in at least the most recent previous block of Spectrum data. Therefore, those targets which are distant in one or more of these target characteristics can preferably be determined to be invalid, at least until they are detected moving in a reasonable manner over a predetermined number of blocks of Spectrum data. For example, since it can be assumed that a target cannot instantaneously (within 0.88 seconds) change speed a target which has a relative speed that cannot be closely matched to a previous target with a comparable relative speed will preferably be considered to be invalid until that target has been tracked for at least some predetermined number of blocks of Spectrum data. In accordance with the preferred embodiment of the present invention, targets are confirmed to be valid if they are detected in at least three consecutive blocks of Spectrum data with target characteristics that are sufficiently close in value.

Determination of Position of Target

The relative position of each target is determined by comparing the range of the target as determined by a first of the Sensor Modules 102 to the range of that target as determined by at least a second of the Sensor Modules 102. In accordance with the preferred embodiment of the present invention, the Sensor Modules 102 are only capable of receiving reflections from targets which lie behind the host vehicle. Therefore, since there are only two points that lie on the plane of the horizon which can satisfy the condition that the target be x distance from the first Sensor Module 102 and y distance from the second Sensor Module, and only one of those points lies behind the host vehicle, the position to each target can be unambiguously determined. In accordance with the present invention, when a target is detected within the Danger Zone, the PM Control Device 301 stores within the non-volatile memory 323, an indication that a target has been detected in the Danger Zone.

In accordance with one embodiment of the present invention, the position of a target is used to determine the validity of that target. For example, in accordance with one embodiment, the target must be within a predetermined area about the host vehicle.

That area may be the same as the area defined as the Danger Zone, or may an area that is slightly larger than the Danger Zone. Furthermore, the position of the target must be within a reasonable distance of a target that was previously determined to be valid, or which has been detected and is within a reasonable distance to a target that was detected in a predetermined number of consecutive previous FFT cycles, such as three in one embodiment of the present invention. If only one sensor detects the presence of a target, that target will not be considered to be valid.

Since the present invention has the ability to determine the position of a target at consecutive points in time, the relative motion of a target can be broken into velocity components along two orthogonal axis. For example, the relative "cross-velocity" (i.e., the velocity transverse to the motion of the host vehicle), and the relative "inward-velocity" (i.e., the velocity in line with the motion of the host vehicle) can each be determined for each target. Accordingly, since the velocity of each target can be determined by two independent methods (i.e., Doppler shift and change in position over time), the validity of each independent method can be verified.

Standby Mode

In accordance with one embodiment of the present invention, PM Control Device 301 enters Standby Mode when the host vehicle is placed in a forward gear. During Standby Mode, a real-time clock is maintained. The real-time clock is used to document the time at which information has been stored within the non-volatile memory 323. In accordance with one embodiment of the present invention, the amount of time that has elapsed since the occurrence of an error is recorded. In such cases, the elapsed time is updated during Standby Mode. In addition, the serial port 319 is preferably monitored. In accordance with one embodiment, the serial communications link may be tested by sending a message and receiving a predetermined response. In no response, or an invalid response, is received, then an error is recorded in the non-volatile memory. In addition, an indicator may be activated to alert the operator of the host vehicle. Furthermore, a Watch Dog Timer may be implemented. Such a Watch Dog Timer is implemented by having a software routine that is to be monitored reset a counter at regular intervals to ensure that the counter does not reach a predetermined value. If the predetermined value

is reached, then an indicator is activated to indicate a failure in either the software routine or the device which executes the software routine that was tasked with resetting the counter.

Operation of the Non-Volatile Memory Interface

In one embodiment of the present invention, a serial interface 321 to the non-volatile memory 323 is provided in accordance with the I^2C standard defined by Philips Semiconductor. The interface is provided by a conventional I^2C controller, such as a model 24C04 serial RAM integrated circuit, distributed by MicroChip Technology of Chandler, Arizona. The I^2C controller offloads time consuming tasks from the PM Control Device 301. When the controller requires service, an interrupt is generated and the source of the interrupt is stored in the Interrupt Status register 325. Preferably, the logic only operates as a master with no waits states in order to minimize the number of gates that are required to implement the Processor Module 100 as a application specific integrated circuit (ASIC). In accordance with one embodiment of the present invention, the serial interface 321 to the non-volatile memory 323 is integrated into an ASIC which includes at least the Sensor Communication Interface 303.

The non-volatile memory 323 is used to store one or more of the following: (1) target range and cross-range at detection of an object; (2) target inward and cross range velocity at first detection; (3) millisecond counter which starts with first detection and ends when either the target is at zero velocity (if the vehicle is at zero prior to the target being at zero velocity) or when the vehicle is at zero velocity (if the target has already reached zero velocity); (4) vehicle speed at first detection; (5) millisecond count (from first detect) to when target enters Danger Zone; (6) target range and cross range when target enters Danger Zone; (7) target inward and cross velocity when target enters Danger Zone; (8) vehicle speed when target enters Danger Zone; (9) millisecond count (from first detect) to when target is at 0.5 Danger Zone distance; (10) target range and cross range when target is at 0.5 Danger Zone distance; (11) target inward and cross velocity when target is at 0.5 Danger Zone distance; (12) vehicle speed when target is at 0.5 Danger Zone; (13) millisecond count (from first detect) to when target is at lost (zero velocity and zero range); (14) target range and cross range just prior to target

being lost (zero velocity or zero range); (15) target inward and cross velocity just prior to target being lost (zero velocity or zero range); (16) vehicle speed when target is lost (velocity or zero range); and (17) possible event triggering criteria.

Non-volatile memory 323 can be read by a service technician to allow diagnostics of the system to be performed. Diagnostic error information is associated with one or more of the following counts: (1) minute count, (2) ignition count, and (3) reverse gear count. Minute count is a count of the number of minutes that an error existed. A counter begins incrementing when one or more errors are set, and stops incrementing when no error exist in the group or when the count reaches a predetermined maximum value. The ignition count counts the number of times the host vehicle ignition was turned on after an error that had detected has cleared. If the ignition count reaches a predetermined maximum value, then each of the counters related to errors are preferably reset. The reverse gear count is a count of the number of times the vehicle is put into reverse gear while an error is being detected. Accordingly, at least one error must exist for the reverse gear count to be incremented.

Serial Port

In accordance with one embodiment of the present invention, a serial port device 319 is provided. The serial port device 319 allows the PM Control Device 301 to communicate with external devices, such as either devices external to, or within, the host vehicle. The serial port is preferably a conventional serial interface, such as a Universal Asynchronous Receive/Transmit (UART) integrated circuit. When service is required by the serial interface, the PM Control Device 301 is preferably interrupted via an interrupt signal generated by the serial port device 319. Upon receiving an interrupt, the PM Control Device 301 preferably reads the Interrupt Status register 325 to determine the source of the interrupt.

Operation of the Indicator Module

In addition, when a target that has been confirmed to be valid and the position of the target is determined to be within a predefined Danger Zone, the PM Control

Device 301 outputs an "Indication Control Signal" which is coupled to the Indicator Module 106 (see Figure 1) on signal line 110.

In accordance with one embodiment of the present invention, the PM Control Device loads the indicator control register 239 with a value that determines which indicator to activate. For example, in accordance with one embodiment of the present invention, an LED is illuminated when a target is detected approaching the Danger Zone, and both the LED and an audible alarm are activated when the target actually enters the Danger Zone. The Indicator Module 106 includes the drive circuits required to activate each of the indicators provided within the Indicator Module 106.

In accordance with the preferred embodiment of the present invention, an Indicator Monitor circuit 241 is provided within the Processor Module 100. The Indicator Monitor circuit 241 preferably senses the status of each indicators. For example, in accordance with one embodiment of the present invention, the amount of current that is being drawn through each indicator in the Indicator Module 106 is monitored to ensure that each indicator is operational and in the proper state. In accordance with the preferred embodiment of the present invention, the Indicator Monitor circuit 241 is simply a connection made from an indicator monitor point 521 to an input to the Processor Module 100 that is capable of detecting the analog voltage level that is present. If the monitor circuit 241 detects an inappropriate condition, a signal is sent from the monitor circuit 241 to the PM Control Device 301. The PM Control Device 301 then logs the condition in the non-volatile memory 323 and attempts to display a system failure indication through the Indicator Module 106. In one embodiment of the present invention, the system failure indicator may be provided using a self contained power supply (such as a battery or separate connection to the automotive electrical system) or may be coupled to the PM Control Device 301 through the serial port 319.

Summary

A number of embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, it is to be understood

that the invention is not to be limited by the specific illustrated embodiments, but only by the scope of the appended claims.

CLAIMS

1. A vehicular radar system for detecting objects to the rear of a host vehicle, the system including:

(a) a first transceiver for transmitting a first transmit signal and receiving reflections of the first transmit signal;

(b) a first range circuit, coupled to the first transceiver, for determining the range of a target from the first transceiver;

(c) a second transceiver for transmitting a second transmit signal and receiving reflections of the second transmit signal, the second transceiver being spaced apart from the first transceiver;

(d) a second range circuit, coupled to the second transceiver, for determining the range of a target from the second transceiver; and

(e) a position determining circuit, coupled to the first and second range circuits, for determining the position of a target detected by both the first and the second transceiver based upon the range of the target from each transceiver.

2. The system of claim 1, wherein the relative velocity of a target is calculated from the change in position of the target over time.

3. The system of claim 1, wherein the position determining circuit determines a set of positions based upon the cross-velocity and inward-velocity components of the relative velocity.

4. The system of claim 2, wherein:

(a) the relative velocity of a target is also calculated from Doppler frequency shift that occurs in the reflection of the transmit signal that reflects off the target and which is received by at least one of the transceivers; and

(b) the validity of a target is checked by confirming that the relative velocity of the target as determined by the Doppler frequency shift is within a predetermined

range of the relative velocity of the target as determined by the change in positions of the target over time.

5. The system of claim 1, further including a first relative velocity circuit, coupled to the first transceiver and to the position determining circuit, for determining the relative velocity of a target based upon the frequency of the received reflections of the first transmit signal, wherein the position determining circuit is also for tracking a first target by:

(a) considering the position of the first target at a first point in time,

(b) determining by extrapolation, based upon the range and relative velocity of the first target, a set of positions which the first target might occupy at a second point in time, and

(c) assuming that a target, detected at a second point in time at one of the positions within the set of positions, is the first target.

6. The system of claim 1, wherein the position determining circuit determines a set of positions based upon the cross-range and inward-range components of a range of the first target.

7. The system of claim 1, wherein the position determining circuit determines a set of positions based upon the cross-velocity and inward-velocity components of the relative velocity.

8. The vehicular radar system of claim 1, wherein the first transceiver includes:

(a) an antenna for transmitting the first transmit signal and for receiving reflections of the first transmit signal off a target;

(b) a generator, coupled to the antenna, for generating the first transmit signal;

(c) a mixer, coupled to the antenna and to the generator, for combining a portion of the output from the generator with the received reflection of the first transmit signal;

(d) an analog to digital converter, coupled to the mixer, for digitizing the output from the mixer; and

(e) a microcontroller, coupled to the analog to digital converter, for controlling the communication of digitized information output from the analog to digital converter in order to provide the digital information to the position determining circuit.

9. The vehicular radar system of claim 8, wherein the position determining circuit includes a control device and wherein the control device within the transceiver transmits the first transmit signal in response to a command sent to the transceiver from the position determining circuit.

10. The vehicular radar system of claim 9, wherein the transceiver further responds to a command sent from the position determining circuit by digitizing the reflection of the first transmit signal received by the transceiver and sending the digital information to the position determining circuit.

11. The vehicular radar system of claim 8, wherein the position determining circuit includes a digital control device for:

(a) receiving digital information from the analog to digital converter;

(b) mapping the digital information from the time domain to the frequency domain;

(c) determining the distance between each target from which the first transmit signal reflected and each transceiver from which a transmit signal originated; and

(d) determining the position of each target based upon the determined distances.

12. The vehicular radar system of claim 1, wherein the position determining circuit defines a danger zone as an area located on the host vehicle side of a line taken

through a set of points, each point located at predetermined distance from each of the transceivers, the danger zone being used to determine when an operator of the host vehicle is to be warned of the presence of the target.

13. The vehicular radar system of claim 12, further including at least one visual indicator coupled to the position determining circuit, wherein the position determining circuit activates the visual indicator upon determining that a target presents a threat of danger.

14. The vehicular radar system of claim 13, wherein the threat of danger is determined based upon the relative location of the target to the danger zone.

15. The vehicular radar system of claim 12, further including an audible indicator coupled to the position indicating circuit for audibly indicating when a target presents a threat of danger.

16. The vehicular radar system of claim 15, wherein the threat of danger is determined based upon the relative location of the target to the danger zone.

17. The vehicular radar system of claim 13, wherein the visual indicator is activated in response to a loss of power to the position determining circuit.

18. The vehicular radar system of claim 1, wherein the first transceiver includes:

(a) a signal generator for generating the first transmit signal;

(b) a control device for causing the frequency of the first transmit signal to alternate between a first and second channel frequency;

(c) a Doppler converter for downconverting the reflections of the first transmit signal to Dopper frequencies; and

(d) an analog to digital converter, synchronized to the control device, for digitizing the amplitude of each received reflection of the first transmit signal such that

a stream of digital words are output in a manner that allows those words that represent the amplitude of reflections of the first transmit signal at the first channel frequency to be distinguished from those words that represent the amplitude of reflections of the first transmit signal at the second channel frequency;

and wherein the position determining circuit is coupled to the analog to digital converter for:

(i) receiving the stream of digital words output from the analog to digital converter;

(ii) mapping a predetermined number of the words that represent the amplitude of the Doppler signal associated with the first channel frequency into the frequency domain from the time domain and outputting a first set of values indicative of the amount of power present at particular frequencies;

(iii) mapping a predetermined number of the words that represent the amplitude of Dopper signal associated with the second channel frequency into the frequency domain from the time domain and outputting a second set of values indicative of the amount of power present at particular frequencies,

(iv) comparing the phase of at least one signal represented by the first set of values with the phase of at least one signal represented by the second set of values and having the same Doppler frequency as the at least one signal represented by the first set of values, to determine the range of a target having a relative speed that is indicated by the Doppler frequency of the two signals having the same Doppler frequency.

19. The system of claim 18, wherein the power represented by the value of words selected from the first set of values is compared to the power represented by words selected from the second set of values, the words selected from the first set of values representing the noise level at selected frequencies in the first channel and the words selected form the second set of values representing the noise level at the same

selected frequencies, but in the second channel, in order to verify the operation of components of the system.

20. The system of claim 18, wherein the power represented by the value of words selected from the first set of values is compared to the power represented by the value of words selected from the second set of values, and wherein the words selected from the first set of values represent a power level which is sufficiently high to indicate the presence of a target, and wherein a target is considered valid only if the difference between the power represented by the words selected from the first and second set of values is with less than a predetermined value.

21. The system of claim 18, wherein the power represented by the value of words selected from the first set of values is compared to the power represented by the value of words selected from the second set of values, and wherein the words selected from the first set of values represent a power level which is sufficiently high to indicate the presence of a target, and wherein a target is considered valid only if the difference between the power represented by the words selected from the first and second set of values is with less than a predetermined value.

22. The vehicular radar system of claim 1, wherein the first transceiver includes:

(a) a signal generator for generating the first transmit signal;

(b) a control device for causing the frequency of the first transmit signal to start at a first frequency and essentially continuously change from the first frequency to a second frequency;

(c) an antenna for receiving reflections of the first transmit signal;

(d) a mixer for mixing the first transmit signal with the received reflections of the first transmit frequency to produce a signal having a frequency that is proportional to the delay between transmission of the first transmit signal and receipt of the reflections of the first transmit signal; and

(e) an analog to digital converter for digitizing the amplitude of each received reflection of the first transmit signal;

and wherein the position determining circuit is coupled to the analog to digital converter for:

(i) receiving the stream of digital words output from the analog to digital converter;

(ii) mapping a predetermined number of the digital words into the frequency domain from the time domain and outputting a set of values indicative of the amount of power present at particular frequencies; and

(iii) determining that a target is present, and the range of the target, based upon the amount of power received at each frequency of the signal produced by the mixer, as indicated by the set of values which result from the mapping from the time domain to the frequency domain.

23. The vehicular radar system of claim 1, wherein the first transceiver includes:

(a) a signal generator for generating the first transmit signal;

(b) a Doppler converter for downconverting the reflections of the first transmit signal to Dopper frequencies; and

(c) an analog to digital converter for digitizing the amplitude of each received reflection of the first transmit signal;

and wherein the position determining circuit is coupled to the analog to digital converter for:

(i) receiving the stream of digital words output from the analog to digital converter;

(ii) mapping a predetermined number of the words that represent the amplitude of the Doppler signal into the frequency domain from the time domain and outputting a first set of values indicative of the amount of power present at particular frequencies; and

(iii) distinguishing a first target from a second target based upon the power present at a first Doppler frequency associated with the first target and a second Doppler frequency associated with the second target.

24. The system of claim 23, wherein a target moving at a first relative velocity at a first moment in time is considered to be the same target as a target determined to be moving at a second relative velocity at a second moment in time, if the difference between the relative velocity of the first target and the second target are within a predetermined range.

25. The system of claim 24, wherein the first and second targets are only considered to be the same target if the first target could have moved from a first position associated with the first target to the position associated with the second target taking into account the relative velocity of the first and second targets.

26. The system of claim 1, further including a non-volatile memory coupled to each range circuit for storing the range of a target from each transceiver.

27. The system of claim 26, wherein the non-volatile memory is also coupled to a control device for causing the range of a target to be stored in the non-volatile memory upon occurrence of a trigger event.

28. The system of claim 27, wherein the trigger event is a determination by the position determination circuit that a target is within a predefined danger zone.

29. The system of claim 28, wherein the trigger event is a determination by the position determination circuit that a target is within a predetermined range of the host vehicle and the relative velocity of the target is greater than a predetermined value.

30. The system of claim 28, wherein the trigger event is a determination by the position determination circuit that a collision between the target and a host vehicle upon which the system is mounted is determined to be unavoidable based upon the relative velocity and the position of the target.

31. The system of claim 28, wherein the trigger event is a determination by the position determination circuit that a collision between the target and a host vehicle upon which the system is mounted is determined to be unavoidable based upon the relative cross-velocity, inward-velocity, and the position of the target.

32. The system of claim 28, wherein the non-volative memory is also coupled to the position determining circuit, and wherein the non-volatile memory is also for storing the position of targets upon occurrence of the trigger event.

33. A method for detecting objects near the rear of a vehicle, using a vehicular radar system having a first transceiver, and a second transceiver, the second transceiver being spaced apart from the first transceiver, including the steps of;

(a) transmitting a first transmit signal from the first transceiver;

(b) receiving reflections of the first transmit signal at the first transceiver;

(c) determining the range of a target from the first transceiver;

(d) transmitting a second transmit signal from the second transceiver;

(e) receiving reflections of the second transmit signal at the transceiver;

(f) determining the range of a target from the second transceiver; and

(g) determining the position of a target with respect to the rear of the host vehicle detected by both the first and the second transceiver based upon the range of the target from each transceiver.

34. The method of claim 33, further including the step of determining the relative velocity of a target from the change in position of the target over time.

35. The method of claim 33, further including the step of determining a set of positions based upon the cross-velocity and inward-velocity components of the relative velocity.

36. The method of claim 34, wherein:

(a) the relative velocity of a target is also calculated from Doppler frequency shift that occurs in the reflection of the transmit signal that reflects off the target and which is received by at least one of the transceivers; and

(b) the validity of a target is checked by confirming that the relative velocity of the target as determined by the Doppler frequency shift is within a predetermined range of the relative velocity of the target as determined by the change in positions of the target over time.

37. The method of claim 33, further including the steps of:

(a) considering the position of the first target at a first point in time,

(b) determining by extrapolation, based upon the range and relative velocity of the first target, a set of positions which the first target might occupy at a second point in time, and

(c) assuming that a target, detected at a second point in time at one of the positions within the set of positions, is the first target.

38. The method of claim 33, further including the step of determining a set of positions based upon the cross-range and inward-range components of the range of the first target.

39. The system of claim 33, wherein the position determining circuit determines a set of positions based upon the cross-velocity and inward-velocity components of the relative velocity.

40. The method of claim 33, further including the steps of:

(a) generating the first transmit signal;

(b) combining a portion of the output from the generator with the received reflection of the first transmit signal;

(c) digitizing the output from the mixer; and

(d) controlling the communication of digitized information output from the analog to digital converter in order to provide the digital information to a position determining circuit.

41. The method of claim 40, transmitting the first transmit signal in response to a command sent to the transceiver from the position determining circuit.

42. The method of claim 41, further including the step of responding to a command sent from the position determining circuit by digitizing the reflection of the first transmit signal received and sending the digital information to the position determining circuit.

43. The method of claim 40, further including the steps of:

(a) receiving digital information from an analog to digital converter;

(b) mapping the digital information from the time domain to the frequency domain;

(c) determining the distance between each target from which the first transmit signal reflected and each transceiver from which a transmit signal originated; and

(d) determining the position of each target based upon the determined distances.

44. The method of claim 33, further including the step of defining a danger zone as an area located on the host vehicle side of a line taken through a set of points, each point located at predetermined distance from each of the transceivers, the danger zone being used to determine when an operator of the host vehicle is to be warned of the presence of the target.

45. The method of claim 44, further including the step of activating a visual indicator upon determining that a target presents a threat of danger.

46. The method of claim 45, further including the step of determining the threat of danger based upon the relative location of the target to the danger zone.

47. The vehicular radar system of claim 45, further including the step of activating an audible indicator based upon the relative location of the target to the danger zone.

48. The method of claim 47, further including the step of determining the threat of danger based upon the relative location of the target to the danger zone.

49. The method of claim 45, further including the step of activating the visual indicator in response to a loss of power to the position determining circuit.

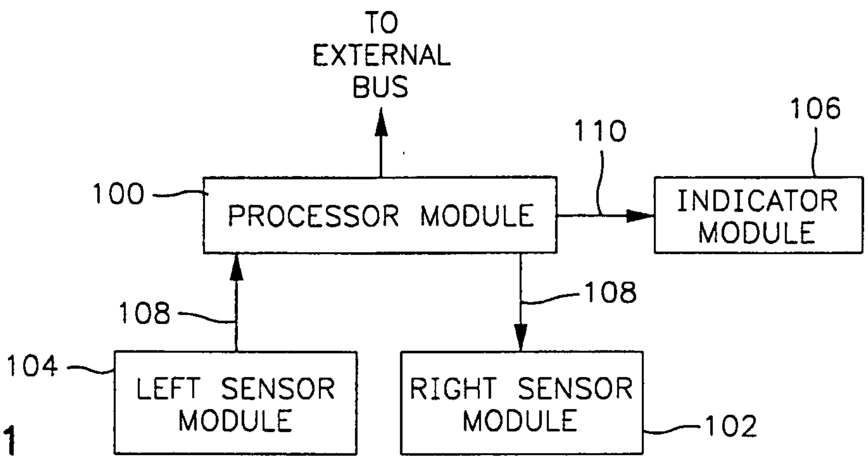


FIG. 1

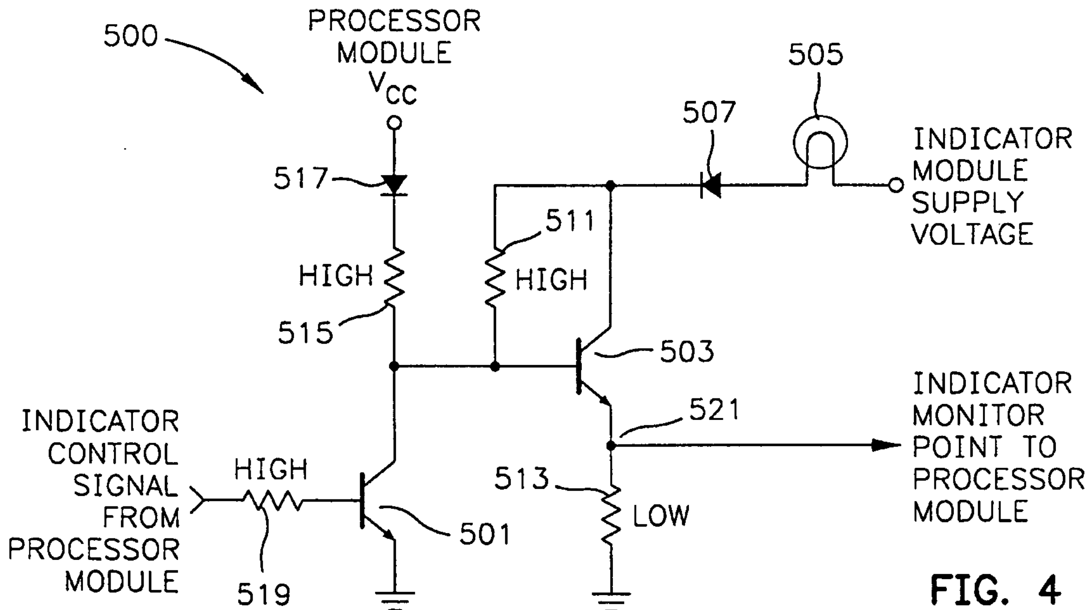


FIG. 4

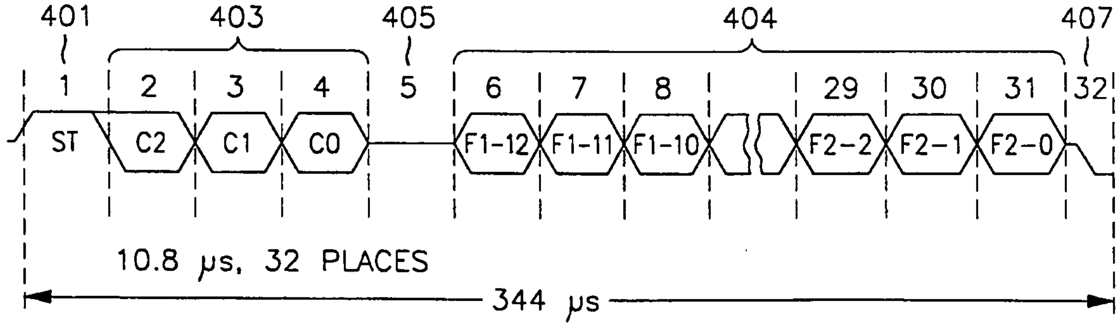
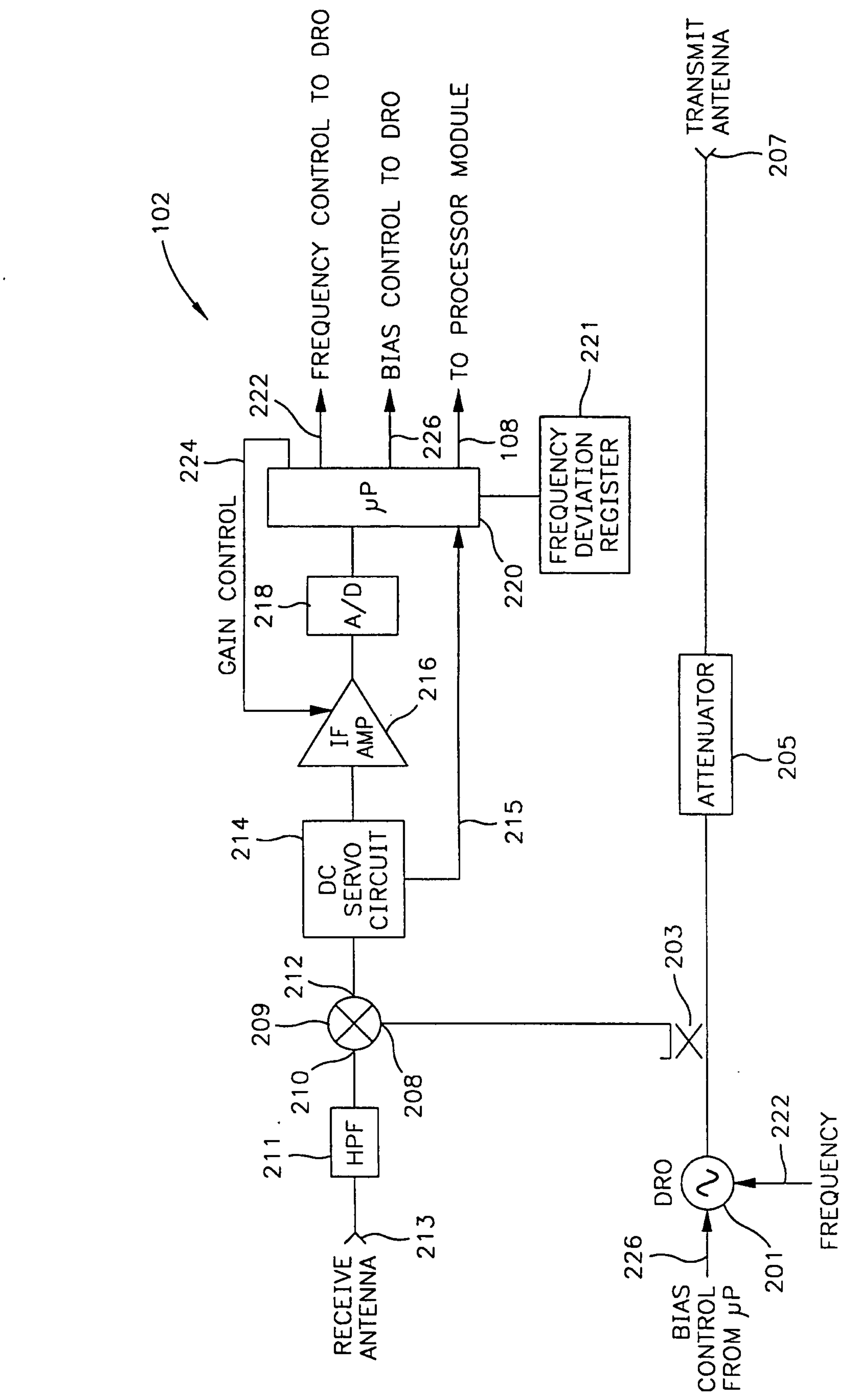


FIG. 5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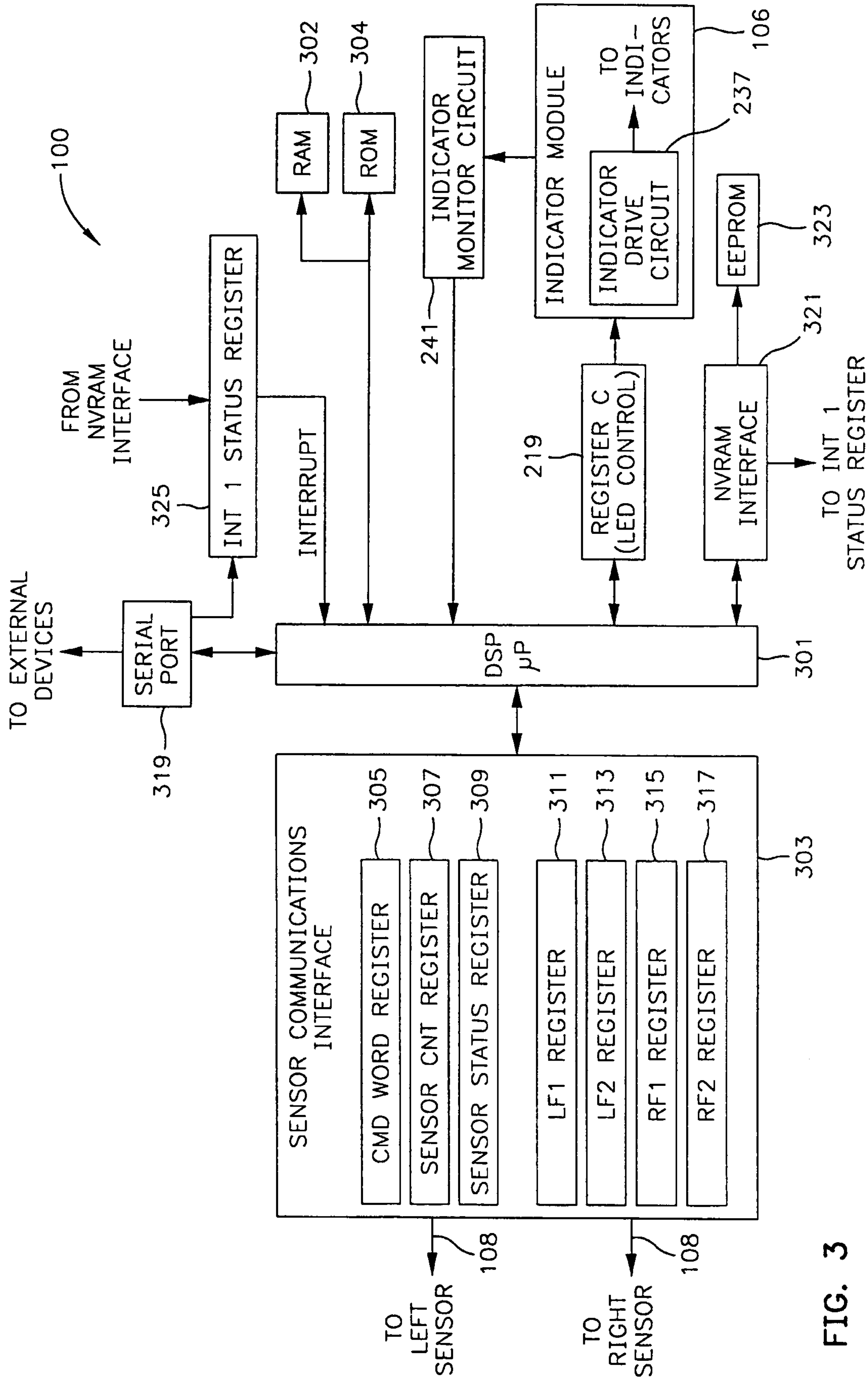
FREQUENCY CONTROL TO DRO
BIAS CONTROL TO DRO
TO PROCESSOR MODULE
222
226
108
224
GAIN CONTROL
μP
220
221
FREQUENCY DEVIATION REGISTER
218
A/D
216
IF AMP
214
DC SERVO CIRCUIT
215
212
209
210
208
211
HPF
213
RECEIVE ANTENNA
203
ATTENUATOR
205
TRANSMIT ANTENNA
207
DRO
201
222
FREQUENCY CONTROL FROM μP
226
BIAS CONTROL FROM μP

FIG. 2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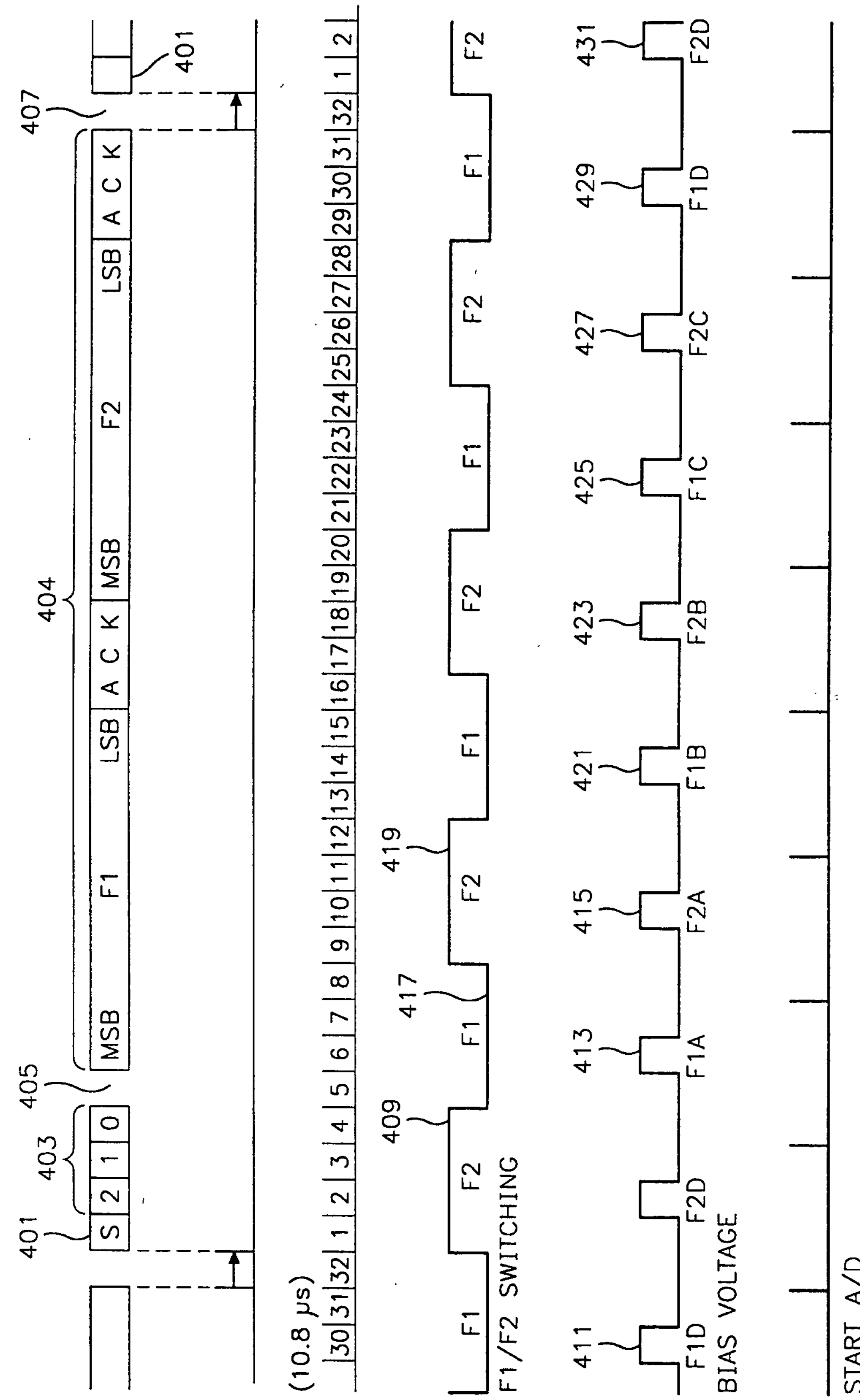
INT 1 STATUS REGISTER
325
INTERRUPT
RAM
302
ROM
304
INDICATOR MONITOR CIRCUIT
241
INDICATOR MODULE
INDICATOR DRIVE CIRCUIT
237
TO INDI- CATORS
106
REGISTER C (LED CONTROL)
219
EEPROM
323
NVRAM INTERFACE
321
TO INT 1 STATUS REGISTER
TO EXTERNAL DEVICES
SERIAL PORT
319
DSP μP
301
SENSOR COMMUNICATIONS INTERFACE
CMD WORD REGISTER
305
SENSOR CNT REGISTER
307
SENSOR STATUS REGISTER
309
LF1 REGISTER
311
LF2 REGISTER
313
RF1 REGISTER
315
RF2 REGISTER
317
303
TO LEFT SENSOR
108
TO RIGHT SENSOR
108

FIG. 3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403
405
404
407
401
S 2 1 0
MSB F1 LSB A C K MSB F2 LSB A C K
(10.8 μs)
30 31 32 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 1 2
409
417
419
F1 F2 F1 F2 F1 F2 F1 F2 F1 F2
F1/F2 SWITCHING
411 413 415 421 423 425 427 429 431
F1D F2D F1A F2A F1B F2B F1C F2C F1D F2D
BIAS VOLTAGE
START A/D

FIG. 6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/19519

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01S13/93 G01S13/87

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 214 748 A (MARCONI GEC LTD) 6 September 1989 see the whole document -----	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

1 Date of the actual completion of the international search 18 February 1998	Date of mailing of the international search report 27/02/1998
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Zaccà, F

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 97/19519

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2214748 A	06-09-89	NONE	